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Training of River Mouths of the Kerala Coast in India

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ABSTRACT

The coastal regions of Kerala are mostly dynamic in nature and is accentuated as the result of various developmental activities taking place along the coastline. Choking of river mouths and sandbar formation is a persistent perennial problem occurring in the tropical states of the Indian sub-continent during non-monsoon seasons. Predominant sediment transport is attributed as a major reason for this occurrence. Critical locations along the Kerala coast were identified to be Cheruvathur, Korapuzha, and Chettuvai. Training of river mouths was identified as the long-term solution for the aforementioned problem, and, hence, the same were proposed for construction after carrying out a detailed study by adopting numerical modeling techniques. The magnitude and direction of the net sediment drift was evaluated. The patterns of shoreline changes corresponding to the proposed training walls were assessed. Wave transformation studies for typical monthly wave climate were performed to analyze the phase and amplitude variation in the presence of proposed structures. The detailed analysis of the results from the numerical model that were analyzed are presented and discussed in this paper. Post implementation of the proposed training walls, desirable effects were yielded.

Keywords: *Training wall, Sandbar formation, Long shore sediment transport, Numerical modeling.*

1. INTRODUCTION

Sandbar formation and chocking of river mouths is one of the most commonly occurring phenomena along the south west coast of India, particularly along the Kerala coast. Herein, the shoreline changes are dynamic in nature, which has resulted due to several developmental activities taking place along the coast. Also, the population distribution is comparatively denser in close proximity to the sea shore because the local population is mostly reliant on fishing related activities. The river mouths along Cheruvathur, Korapuzha, and Chettuvai were identified to undergo severe choking and predominant sandbar formation, preventing the ease of flow of river stream water into the ocean. The main objective of this paper is to discuss the proposed training of river mouths at Cheruvathur and to highlight a similar study at Korapuzha and Chettuvai along the coast of Kerala.

2. DESCRIPTION ABOUT THE STUDY AREA

Cheruvathur is a coastal town is located at 13˚13’N and 75˚7’60’’ E along the south west coast of India. The Chandragiri river flows through this town and eventually drains into the Arabian Sea. The site experiences a predominant net southerly drift of sediment transport, resulting in sandbar formation at the confluence of the river and Arabian Sea. This necessitated a detailed study on suitable remedial to prevent the sandbar formation and to establish a smooth flow of water from the river into the Ocean. The proposed measure should also beneficially satisfy the needs of the fishermen community, where it could also alleviate maneuvering problems of fishing boats.

3. LITTORAL DRIFT ESTIMATE

From visual observation and the by the experience of the local departments, the site was identified to undergo a net southerly drift of sediment transport. However, to devise an efficient plan and design, both magnitude and the direction of the net drift had to be estimated. Therefore, the distribution of longshore currents across the surf zone and the monthly sediment transport estimate based on energy flux method has been predicted using Komar (1969), CERC (1984), and by integrating the distribution across the surf zone (Komar, 1976).

4. NUMERICAL MODEL FOR WAVE TRANSFORMATION

The combined refraction-diffraction equation that describes the propagation of periodic, small amplitude surface gravity waves over an arbitrarily varying mild sloped sea bed according to (Berkhoff, 1972), and also discussed by Li (1994), is

$$\nabla . CCg \nabla \varphi + \frac{Cg}{C} \sigma^2 \varphi = 0 \tag{1}$$

where φ - Complex velocity potential
σ - Angular wave frequency
C - Phase celerity and
Cg - Group celerity.

The above equation is transformed into a Helmholtz equation of the form,

$$\nabla^2 \phi + K^2 (x, y) \phi = 0 \tag{2}$$

using the following relations

$$\phi = \varphi (CCg)^{0.5} \; and \; K^2 = k^2 - \frac{\nabla^2 (CCg)^{0.5}}{(CCg)^{0.5}} \tag{3}$$

where k = wave number
K and ϕ are modified wave number and Wave potential function

A finite difference scheme is employed for the numerical discretization of Helmholtz equation. The derivatives are approximated using centered difference scheme. Writing the discretized form of the Eq. for each grid in the domain and applying suitable boundary conditions, the system of resulting algebraic equations can be written in matrix form as

$$A\phi = f \tag{4}$$

Where 'A' is the coefficient matrix, ϕ is the nodal values of velocity potential, and f is a vector obtained from the boundary conditions. The numerical solution of the above system of equations is arrived using generalized conjugate gradient method. The method successively estimates new approximations to the solution, considering the direction of residual error vector, till the prescribed accuracy is achieved. The offshore boundary is modelled as an open boundary in which case-only incident waves and reflected waves are allowed to propagate. The lateral boundary as well as the shore is considered to absorb the wave energy. The groins or any other obstruction is treated as partially reflecting boundaries by prescribing the reflecting coefficients. The model requires the wave characteristics (viz. wave height, wave period, and direction) and the water depths at all the grid points. It also requires the location of the groins. The model gives the wave characteristics inside the domain. The Department of Ocean Engineering, IIT Madras has developed numerical models on the diffraction-refraction of waves due to the presence of near-shore structures. The model is developed using the mild slope equation because of its generality in dealing with complex wave fields. The mild slope equation is solved by generalized conjugate gradient method as it has a fast convergence rate.

5. SHORELINE EVOLUTION MODEL

5.1. Prediction of Offshore Boundary Data

Snell's law (also known as Snell-Descrates law and the law of refraction) that governs the wave refraction is given by

$$\frac{\sin \theta_0}{\sin \theta} = \frac{C_0}{C} \quad (5)$$

where, C_0 is the deep water wave celerity (deep water wave length Lo = 1.56 T2) and C is the wave celerity. The angle conventions for the seabed contours, as well as for the wave direction used for the numerical model are shown in Figure.1.

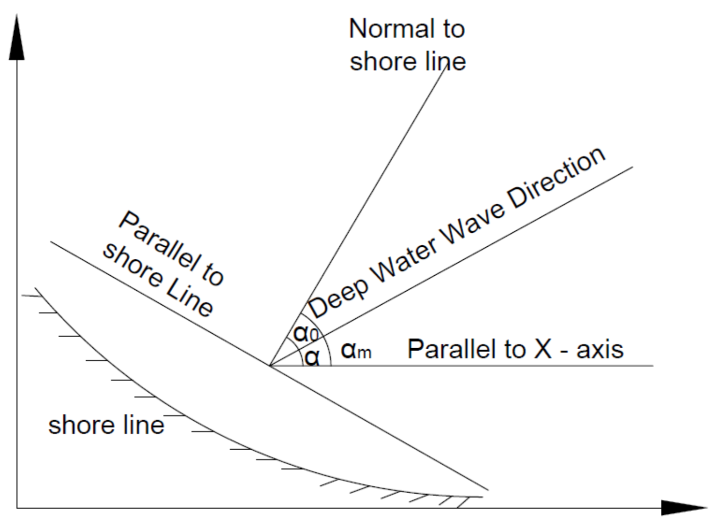

Figure 1. Angle conventions used in the numerical model.

The deep-water wave angles were converted to that corresponding to shallow waters through the Snell's law, taking into consideration of the inclination of shoreline with respect to geographic North. These shallow water wave angles were then expressed with reference to shore normal according to the angles conventions employed in the present numerical model. The conservation of energy while the wave propagates from deep to shallow waters is adopted to obtain the wave height at shallow water depth, i.e., the offshore boundary for the wave transformation model.

There are several configurations of coastal protection structures with respect to the shoreline, among which structures normal to the shore are most common. The construction of a shore-connected structure often leads to changes in the shoreline. This warrants a study on the shoreline due to presence of the shore-connected structures. Such a study is very much essential in planning stage, so as to assess the impact of shore connected structures on the adjacent shoreline. Numerical models offer the capability to study the effect of the wave characteristics, structure dimensions and other associated parameters in providing reasonable estimates of the shoreline response. When a structure is constructed normal to the shoreline, it will intercept the free passage of longshore sediment transport, resulting in an imbalance in the quantity of sediment in the near shore, especially near the structure. This leads to accretion on the up drift side and erosion on the down drift side of the structure. The Department of Ocean Engineering, IIT Madras has developed numerical models on the prediction of shoreline changes due to the presence of near-shore structures.

5.2. Mathematical Formulation

KRAUS and HARIKAI (1983) proposed a numerical scheme to solve the one-line model using Crank Nicholson implicit finite difference method. The non-dimensional equation of shoreline is written as

$$y^*_{n,t^*+1} = B\left\{Q^*_{n,t^*+1} - Q^*_{n+1,t^*+1}\right\} + C_n \tag{6}$$

where,

$$B = \frac{\delta t^*}{2 \times \delta x^*} \; and \; C_n \; = B\left\{Q^*_{n,t^*} - Q^*_{n+1,t^*} + 2\delta x^* q^*_{n,t^*}\right\} + y^*_{n,t^*}$$

The non-dimensional shoreline is divided into '*n*' grid points at equal non-dimensional interval, δx^*. Then shoreline changes over a non-dimensional time, δt^* is calculated using Crank-Nicholson finite difference scheme.

In this method, Q^* at the time interval (t^* +1) is expressed in terms of the shoreline co-ordinate of y^*, first isolating the term involving α_{sp} (angle of shoreline normal to x-axis) using trigonometric identities. One of the term involving α_{sp} is then expressed as first order quantities in y^* at time step (t^*+1).

$$Q^* = K_D^2 \cos\left(\alpha_o\right) \sin\left(\alpha_b\right) \tag{7}$$

where, $\alpha_o = \alpha - \alpha_{sp}$ and α is wave direction with respect to x-axis. The elliptical form of mild slope equation, which deals with combined refraction diffraction is defined as

$$Q^* = K_D^2 \cos\left(\alpha - \alpha_{sp}\right) \sin\left(\alpha_b\right)$$

$$Q^* = K_D^2 \sin\left(\alpha_b\right) \left\{\cos\left(\alpha\right)\sin\left(\alpha_{sp}\right) \cot\left(\alpha_{sp}\right) + \sin\left(\alpha\right) \sin\left(\alpha_{sp}\right)\right\} \tag{8}$$

$$Q^* = E_n \left\{y_{n-1,t^*+1} - y^*_{n,t^*+1}\right\} + F_n$$

where,

$$E_n = K_D^2 \left\{\cos(\alpha)\sin\left(\alpha_{sp,t^*}\right)\sin\left(\alpha_{b,t^*}\right)\right\} / \delta x^* \; and \quad F_n = K_D^2 \left\{\sin\left(\alpha_{sp,t^*}\right)\sin\left(\alpha_{b,t^*}\right)\right\}$$

Substituting the above equations gives the final equation, as given below:

$$BE_n\, Q^*_{n-1,t^*+1} - \left(1 + 2BE_n\right)Q^*_{n,t^*+1} + BE_n\, Q^*_{n+1,t^*+1} = E_n\left[C_n - C_{n-1}\right] - F_n \tag{9}$$

The above equations represent a set of (N-1) linear equation for (N-1) unknowns. The end values are specified as boundary conditions, that is, $Q^*_1 = 0$ and $Q^*_{N+1} = Q^*_N$. The above equation results into a tridiagonal form, which is solved for Q^*. This process is repeated for the entire duration, and any non-dimensional quantity is converted into real quantities using the corresponding scale factors. The program has been validated with published results. The coastal line is discretized into number of grids with an equal spacing of 10m. The co-ordinates of the existing shoreline were provided. The length of the structure and grain size of the sediments required for the calculation of active depth of the sediment transport and water depth at the tip of the structure are the inputs given to the model. In addition to these, the monthly wave characteristics and the number of years over which the shoreline change is desired to be mentioned. The output shows the predicted shoreline changes after a period of 1, 5, 10, 15, 20, and 25 years. The upstream of the structures shows advancement of the shoreline position, while, the downstream end shows the erosion.

6. RESULTS AND DISCUSSIONS

6.1. Cheruvathur

The site understudy has an existing pair of jetties in the north and south of the Mandakara creek, and after a detailed study and analysis, a pair of training walls were proposed to be constructed such that the creek remains open and the tidal inlets enters the basin thereby promoting ease of flow from the stream into the sea and also avoiding sandbar formation. Figure 2 shows the layout- of proposed training walls. Figure 3 shows the location map of the site before and after the construction of training walls.

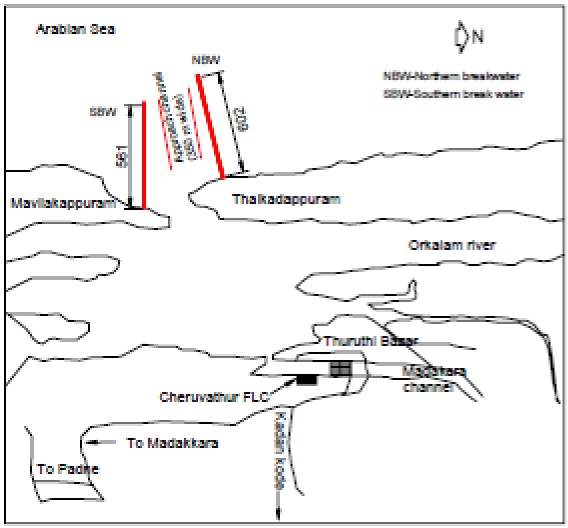

Figure 2. Layout of the proposed training wall

Figure 3. Google earth imagery of Cheruvathur

6.2. Littoral Drift and Shoreline Evolution

The wave data from NIO wave atlas (Chandramohan *et al.,* 1990) has been analyzed to obtain the average wave height, wave period and wave direction, from which the average breaking wave characteristics were derived. Table 1 show the monthly predominant deep water wave direction and Table 2 provides the wave characteristics used for tranquility studies. The results indicate that the mean breaker height varies from about 0.9 to 1.9m. The breaker height is observed to be a maximum of the order of 1.76m and 1.94m during the months of June and July respectively. The wave direction is towards north only during the months of May and June, whereas, for all other months it is towards the south. The net sediment transport from the above three methods was computed to be in the order of $0.6 x 10^6$ cu.m/yr. Figure 4 shows the monthly sediment transport rate at Cheruvathur.

Table 1. Monthly predominant wave climate

Month	**θ_o (deg)**
January	300 –360
February	300-360
March	300-360
April	270-360
May	230-320
June	230-300
July	250-290
August	250-290
September	280-300
October	260-310
November	340-360
December	340-360

Table 2. Wave characteristics for tranquility studies

Month	**H_{avg} (m)**	**T (s)**	**θ (deg)**
January	1.25	6.5	-36
February	1.25	6.5	-36
March	1.25	6.5	-36
April	1.25	6.5	-20
May	2.5	7.5	6
June	2.5	7.5	6
July	2.75	7.5	-6
August	2	7.5	-6
September	1.75	6.5	-26
October	1.25	6.5	-13.5
November	1.25	6.5	-42
December	1.25	6.5	-42

Where H_{avg} - Average wave height; T - Wave period; θ - Wave angle with respect to shore normal
θ_o – Deep water wave direction with respect to geographic North

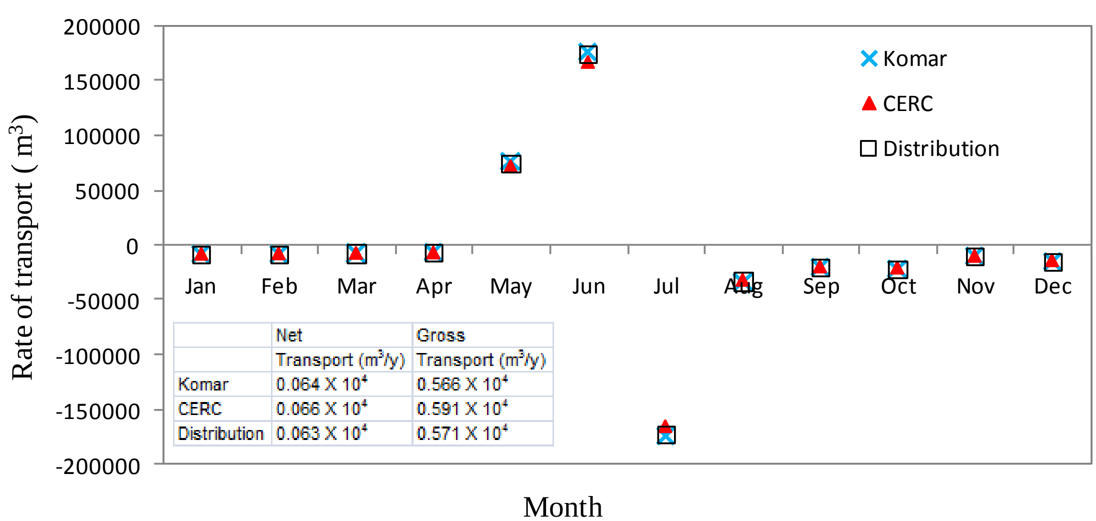

Figure 4. Monthly sediment transport rate at Cheruvathur

The numerical model to predict the shoreline evolution due to the shore-connected structures has been used to predict the shoreline changes due to the proposed training walls. The numerical model has run for finally recommended layout, discussed under section 6.5**.** The grain size (*D50*) is 0.25mm. The wave characteristics given as the input to the numerical model are as per Table 2. The length of the training wall, water depth at the end of the breakwater, and the present status of the shore are given as the input to the numerical model. The numerical model has run for the mean wave heights for different months, and the corresponding shoreline changes are shown in Figure 5.

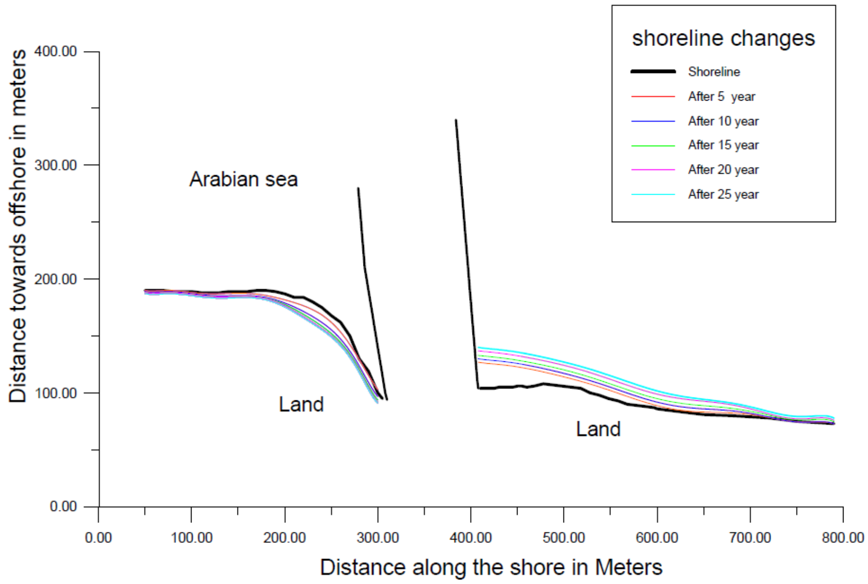

Figure 5. Variation of shoreline over the years

The cumulative effect of the wave characteristics and the presence of the breakwaters on the adjoining shorelines have been studied. The results indicate the shoreline advancement towards the ocean on the north of NBW is effectively over a distance of about 150m. This is the effect over a period of 25 years. The shoreline near the breakwater is expected to advance to a distance of about 50m towards the ocean. However, the discharge from the river Cheruvathur will wash away the sediments into deeper ocean, particularly during the months June to August. In order to ascertain the washing away of the sediments that are likely to be deposited near the mouth, the fall velocity W was calculated for the mean grain size, *D* of 0.25mm and with the empirical relationship $W = 6.5 \; X \; D^{1/2}$, where *D* and *W* are in m and m/s, respectively. In this way, the fall velocity works out to be 0.1m/s. This is extremely small compared to the velocity in the river Cheruvathur. On the southern side, the erosion is seen to take place over a period of 20 years, which is, however, much less.

6.3. Wave Tranquility Studies

The total stretch considered for the numerical modeling is 2.42 km along the shoreline and up to 5m bottom contours in the offshore-onshore direction. The numerical model has been executed for the proposed layout with the wave characteristics as reported in the above table.

Typical results on the distribution of wave height and wave phase contours for the month of January, February, and March with shore normal angle of -36° is evaluated Figure 6. Due to the irregularity in the bathymetry, the waves are found to be steep at certain locations in the area towards the sea away from the breakwater. The phase contours clearly demonstrates the phenomenon of wave diffraction. The bending of the wave fronts and penetration into the harbour basin are clearly seen. Figure 6 shows the wave height and phase contours for the wave characteristics for the months January to March.

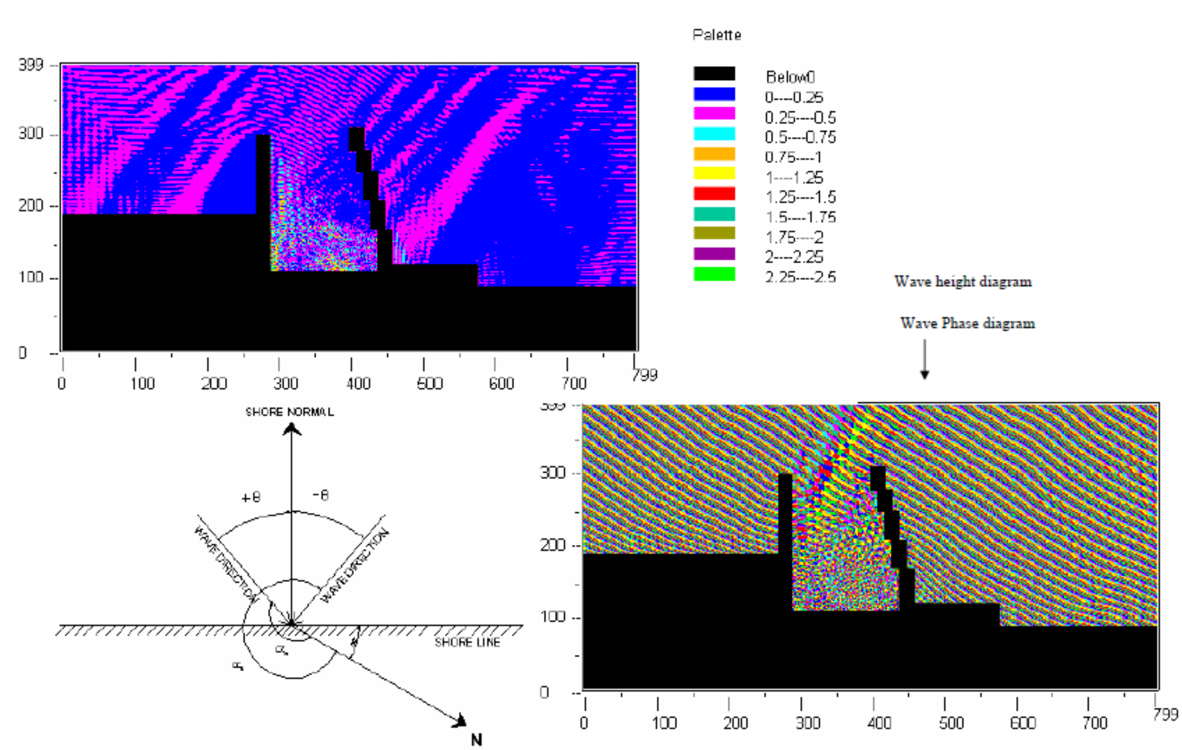

Figure 6. Wave height and phase contours for H_{avg} =1.25m, T=6.5s, θ=-36°

7. SIMILAR PROJECTS

Similar problems of river mouth choking and sandbar formation was also observed at these sites. Training of river mouths was evaluated as a viable solution. The imageries on the results from the other sites, namely Korapuzha (11° 9'41.44"N and 75°48'11.40"E), Chettuvai (10°30'32.26"N and 76° 2'20.14"E), Perumanathura (8°37'59.41"N and 76°47'11.98"E), and Beypore (11° 9'41.10"N and 75°48'11.70"E) are projected in Figs 7, 8, 9, and 10, respectively.

Figure 7. Google earth imagery of Korapuzha

Figure 8. Google earth imagery of Chettuvai

Figure 9. Google earth imagery of Perumanathura

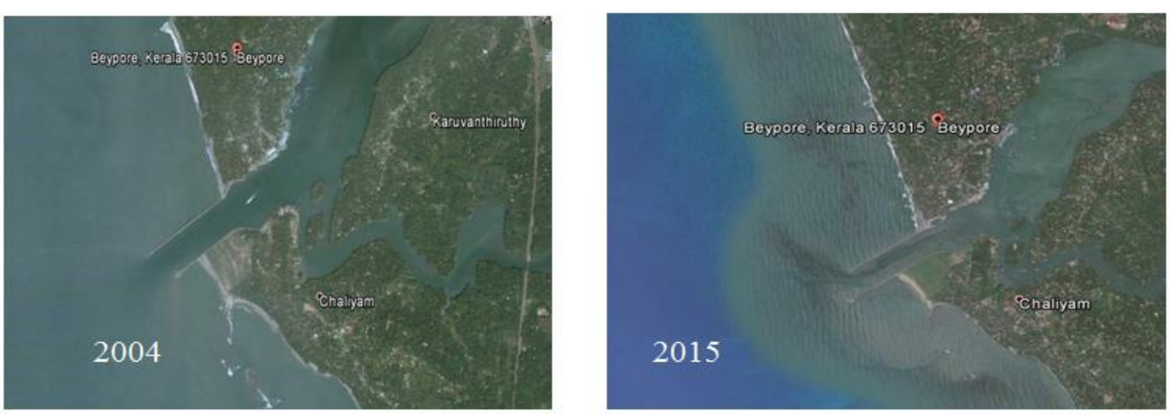

Figure 10. Google earth imagery of Beypore

8. CONCLUSION

We discussed in detail the process of training of river mouths in Kerala coast at Cheruvathur, Chettuvai, and Korapuzha. Every detail is designed with consideration of wave action of storm surge. Littoral drift estimates quantify the magnitude, and direction of sediment transport and the shoreline behavior post construction of the proposed measure is evaluated through numerical modeling, and it clearly demonstrates the effectiveness of the training walls.

9. REFERENCES

Berkhoff, J. C. W. (1972), "Computation of combined refraction–diffraction", *Proceedings 13th International Conference on Coastal Engineering*, Vancouver, pp. 471–490

Chandramohan, P.; Sanil Kumar, V., and Anand, M., (1990). "*Wave* Atlas for the Indian Coast", Goa, India:National Institute of Oceanography, Ocean Engineering Division, 312 p.

Kraus, N.C., and Harikai, S. 1983. Numerical Model of the Shoreline Change at Oarai Beach. Coastal Engineering, 7(1), 1-28.

Komar, P.D. (1976a), "Beach process and sedimentation", *Prentice –Hall Englewood Cliffs, N.J.*, 429p.

Komar, P.D. (1976b), Longshore currents and sand transport on ocean Eng. III, *ASCE* ,pp 333-354.

Li, B. (1994). "Generalized Conjugate Gradient Model for the Mild Slope Equation.", *Coastal engineering journal*, Vol. 23, pp-215-225.